Terahertz meta-optics made with ultrashort pulse laser processing

Haruyuki Sakurai, Kuniaki Konishi
Institute for Photon Science and Technology, The University of Tokyo
kkonishi@ipst.s.u-tokyo.ac.jp

The technology to control electromagnetic waves by using artificial structures of the same or smaller size as the wavelength is called metamaterials or metasurfaces, and by appropriately designing their shapes, it is possible to control their optical response in various ways. Electromagnetic waves in the frequency range of 0.1 to 10 THz are called terahertz waves, and in recent years, they have attracted attention not only for fundamental science but also for applications in sensing, wireless communications, and radio astronomy.

Although lithography techniques are generally used to fabricate micro-scale artificial structures, it is not easy to fabricate non-uniform structures in the height direction because the technique is good at fabricating structures in a two-dimensional plane. In addition, multiple micro-processing devices and clean-room environments are required to perform a series of processes, which are costly to maintain.

Recently, femtosecond laser processing technology has attracted attention as a new method for fabricating 3D structures. In a laser processing system using an ordinary galvanometer mirror, the focusing diameter of the beam is about 10 to 20 μm, which is sufficiently smaller than the typical wavelength of terahertz waves, which is several hundred μm. Therefore, it is possible to fabricate 3D microstructures below the terahertz wavelength by femtosecond laser processing, and it is expected to be a tool for fabricating terahertz metamaterials as an alternative to lithography.

In this talk, I will introduce the development of artificial microstructures such as large-area anti-reflective moth-eye structures and terahertz meta-lenses for terahertz wave control using ultrashort pulse laser processing, which is under study in our group. We have succeeded in fabricating an anti-reflective moth-eye structure with nearly 100% transmittance in the sub-terahertz region [1,2] (Fig. 1) and further enlarged it to 300 mm in diameter [3]. This structure has been implemented in a radio telescope for the first time and is currently in operation. It has also been reported that Huygens membrane metalens in the terahertz frequency region can be fabricated by using lithography to create appropriately designed holes in a thin silicon substrate [4]. We have successfully fabricated similar meta-lenses with femtosecond lasers.

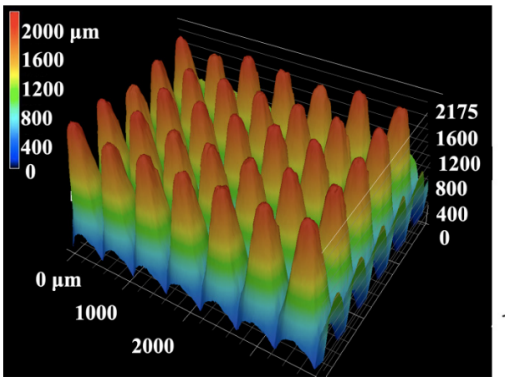

Fig. 1 Microscopic image of terahertz moth-eye structure fabricated by femtosecond laser processing.

Such laser fabrication techniques for meta-optics have the potential to fabricate large-area structures that could not be made with conventional lithography, and to dramatically simplify fabrication methods.

References

[1] Haruyuki Sakurai, Natsuki Nemoto, Kuniaki Konishi, Ryota Takaku, Yuki Sakurai, Nobuhiko Katayama, Tomotake Matsumura, Junji Yumoto, Makoto Kuwata-Gonokami, OSA Continuum, **2**, 2764 (2019).
[2] R. Takaku, S. Hanany, H. Imada, H. Ishino, N. Katayama, K. Komatsu, K. Konishi, M. Kuwata-Gonokami, T. Matsumura, K. Mitsuda, H. Sakurai, Y. Sakurai, Q. Wen, N. Y. Yamasaki, K. Young, J. Yumoto, Journal of Applied Physics **128**, 225302 (2020).
[3] Ryota Takaku, Qi Wen, Scott Cray, Mark Devlin, Simon Dicker, Shaul Hanany, Takashi Hasebe, Teruhito Iida, Nobuhiko Katayama, Kuniaki Konishi, Makoto Kuwata-Gonokami, Tomtoake Matsumura, Norikatsu Mio, Haruyuki Sakurai, Yuki Sakurai, Ryohei Yamada, Junji Yumoto, Optics Express **29**, 41745-41765 (2021).
[4] Yuki Hakamada, Mizuho Matoba, Haruyuki Sakurai, Kuniaki Konishi, "Fabrication of THz metalens by ultraviolet femtosecond laser ablation" SPIE Photonics West 2024 (San Francisco, USA)